

A Development of Piezoelectric Model as an Energy Harvester from Mechanical Vibration

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Energy harnessing has gain much interest and become more essential to achieve environment sustainability. By harnessing ambient energy from the environment, it will reduce the electricity energy consumption. Nowadays, vibration energy shows a promising amount of energy generation. This paper presents the modelling for conversion of mechanical vibration into electricity using piezoelectric converter. The model development was based on the piezoelectric model of PI P-876 and the non –adaptive rectifier circuit was employed in order for direct voltage conversion that are much useful for electronic devices nowadays. Several sources of vibration energy literally reviewed such as ducting and piping system which then fed into the piezoelectric model converter in Matlab SIMULINK. As a result, a maximum direct voltage of 0.14 V and 1.96 Watt of energy could be harnessed from ducting system. This power output is sufficient for mini home appliances and low-powered wireless sensor networks in silent mode which can be used in variety of applications.

1. Introduction

Energy harvesting or also known as power harvesting is actually process whereby the energy or power obtain from environment, converting to electricity, and lastly storing for the usage of electronic devices. There are wide range of sources of energy harvesting technologies such as acoustic (Bin Li et.al., 2013), thermal energy (Yen K. T and Sanjib K. P., 2010), mechanical vibration (Shenck and Paradiso, 2001), wind energy (Devine – Wright, 2010), solar energy (Green et.al., 2015) and many more. The benefit of energy harnessing is to minimize or reduce the needs of internal source of energy that used in daily life. This is very importance for environmental friendly and save the world for the future generation. In addition, harvesting ambient energy has a great potential and can be used extensively because it's essentially free and have a clean conversion mechanism.

One of the ambient energy sources that has received attention form researchers for energy harnessing is vibration which can be observed in buildings (Erturk and Inman, 2009), vehicles (Beeby et.al., 2004), industrial machineries (Chiu and Tseng, 2008). Typically, vibration energy can be converted into electric energy by three methods, namely electromagnetic (inductive), electrostatic (capacitive) and piezoelectric conversion. However, piezoelectric conversion has shown a promising performance in harnessing vibration energy. According to Roundy et.al. (2003), the energy density of piezoelectric transducers is three times higher compared to electrostatic and electromagnetic transducers. Table 1 shows a comparison of potential energy sources with a fixed level of power generation and a fixed amount of energy storage (Mat Darus et.al., 2013). The data tabulated in Table 1 shows that a promising amount of power density can be harnessed from vibration energy, which ranging from 50 to 200 $\mu\text{W}/\text{cm}^3$.

Vibration is the most attractive energy harvesting solution while piezoelectric has shown a great potential, thus it is the best interest to study the potential of piezoelectric converter to harness vibration as a feasible power source for applications. Several sources of low level vibration were determined and fed into piezoelectric model in order to find the maximum electricity generated. Harvesting vibration energy is very important as the initiative to provide a completely self-powered system.

Table 1: Comparison of Potential Energy Sources with a Fixed Level of Power Generation and a Fixed Amount of Energy Storage

Sources	Power Density ($\mu\text{W}/\text{cm}^3$) 1-y lifetime	Power Density ($\mu\text{W}/\text{cm}^3$) 10-y lifetime
Solar (outdoors)	15,000 – direct sun 150 – cloudy day	15,000 – direct sun 150 – cloudy day
Solar (indoors)	6 – office desk	6 – office desk
Shoe inserts	330	330
Temperature gradient	15 at 10 °C gradient	15 at 10 °C gradient
Vibration (electromagnetic conversion)	100	100
Vibration (electrostatic conversion)	50	50
Vibration (piezoelectric conversion)	200	200
Batteries (non-rechargeable lithium)	45	3.5
Batteries (rechargeable lithium)	7	0
Hydrocarbon fuel (micro heat engine)	333	33
Fuel cells	280	28

2. Energy harnessing using Piezoelectric materials

Wasted vibration energy from environment is utilize rather than letting it dissipates. The concept of vibration energy harnessing can be illustrated as in Figure 1. Piezoelectric materials are used to harness this wasted energy and converting it into electrical energy, which can later be utilized for powering electronic appliances or devices.

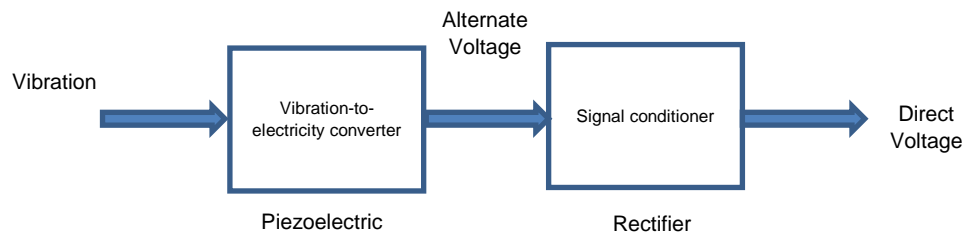


Figure 1: Concept of vibration energy harnessing

Initially, the mechanical vibrations have been identified which commonly occurring vibration from different types of sources as shown in Table 2. The measured vibration sources are represented in terms of their acceleration magnitude and frequency of fundamental vibration mode.

Table 2: Measured vibration from various sources

Vibration source	Acceleration of amplitude (m/s^2)	Frequency of peak (Hz)
Railway	91.00	2372
Industrial motor	38.36	1000
Kitchen blander casing	6.40	121
Ducting system (HVAC Vents)	1.50	60
Piping system	0.38	10

A vibration sources from blander casing, ducting and piping system has been used as the basis, which at range of 6.4 – 0.38 m/s^2 and 121 – 10 Hz. The source can be classified as the middle of wide range of low level vibration sources in terms of power output. Thus, it can be considered as a representative of vibration sources in this study.

3. Methodology

The simulation setup of piezoelectric converter used in this study can be described by modelled the piezoelectric material and the non-adaptive circuit of rectifier. The flow of the process and technique used to harness vibration energy as illustrated in Figure 1. The simulation in Matlab SIMULINK has been done using vibration data acquired from experimental study by previous researcher as in Table 2. The piezoelectric converter determined the possible amount of power density output that can be produced for the specific acceleration input. With the promising amount of power density output produced during simulation, electronic appliances or devices can be identified which can fully utilize this power.

Every piezoelectric patch has their own mathematical model based on their size, mass, active area, range of operating area and others. In this study, piezoelectric patch of PI P-876 DuraAct transducers is our interest due to its fast response of any disturbance changes. From previous experimental study by Maslan et.al. (2012), the transfer function for piezoelectric patch of PI P-876 DuraAct transducers were determined and validated as:

$$G^{-1} = \frac{-0.04314 + 0.07153z^{-1} - 0.0284z^{-2}}{0.4795 - 1.487z^{-1} - 0.0071z^{-2}} \quad (1)$$

Where z is the discrete time transfer function. Piezoelectric model as in Eq(1) was adapted in this study. It is worth to note that piezoelectric material produces alternate voltage when it is mechanically deformed. Thus, the non-adaptive rectifier circuit presented by Mingjie and Wei-Hsin (2005) was used because it has been proved more power can be harnessed as compared with adaptive circuit proposed by Ottman et.al. (2002). The non-adaptive rectifier circuit was utilized as the harnessing circuit to rectify the alternate voltage produced by piezoelectric converter, thus can be fully utilize by most of the electronic devices that powered by direct voltage. The non-adaptive circuit is illustrated in Figure 2 which includes a conventional diode bridge rectifier and a passive circuit. Diodes are used in this circuit and it is assumed that there is no voltage drop across it. Capacitance value, C for the filtering capacitor is calculated by using Eq(2) where i is the load current across the capacitor, V_p is the bridge rectifier output peak voltage and f is the frequency of the AC supply taken at 10 Hz.

$$C = \frac{5i}{V_p f} \quad (2)$$

$$V = IR \quad (3)$$

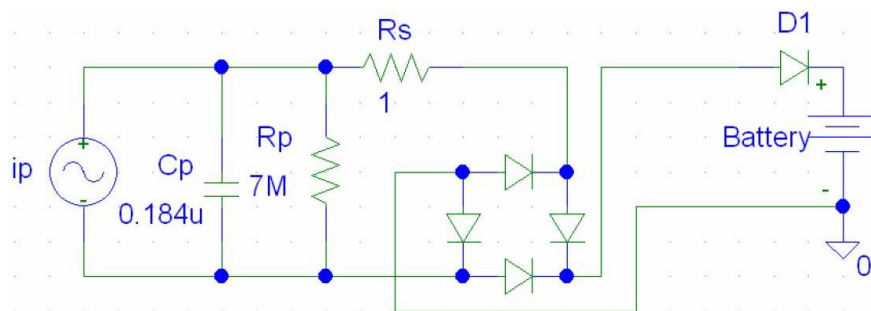


Figure 2: Non-adaptive harnessing circuit (Mingjie and Wei-Hsin, 2005)

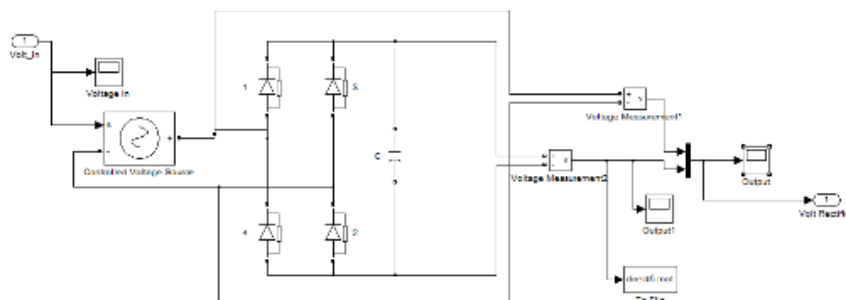


Figure 3: Matlab SIMULINK diagram for the non-adaptive harnessing circuit

The value of load resistance, R is determined by using the basic electric law which is Ohm's Law as given by Eq(3), where V is the voltage across it and I is the current. The non-adaptive harnessing circuit that was simulated in Matlab SIMULINK environment is shown in Figure 3. Data for voltage input was taken from piezoelectric converter model simulated in the Matlab SIMULINK environment earlier. The flow process of the simulation setup for piezoelectric converter and the non-adaptive rectifier circuit used in this study as illustrated in Figure 4.

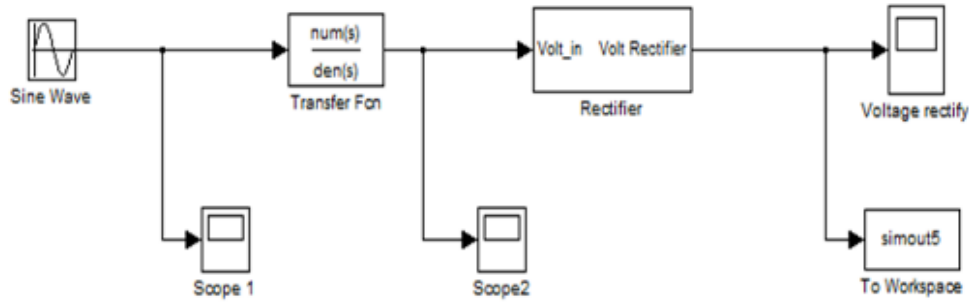


Figure 4: Matlab SIMULINK diagram for piezoelectric vibration converter

4. Results and discussion

Based on the model developed, the output from the system can be identified and analysed. The results of the simulation conducted includes direct voltage generated from various vibration sources. Firstly, the vibration sources at different acceleration input (m/s^2) was represented in Matlab SIMULINK as sine wave input. Figures 5a, b, and c show the vibration input from kitchen blender casing, ducting and piping system respectively.

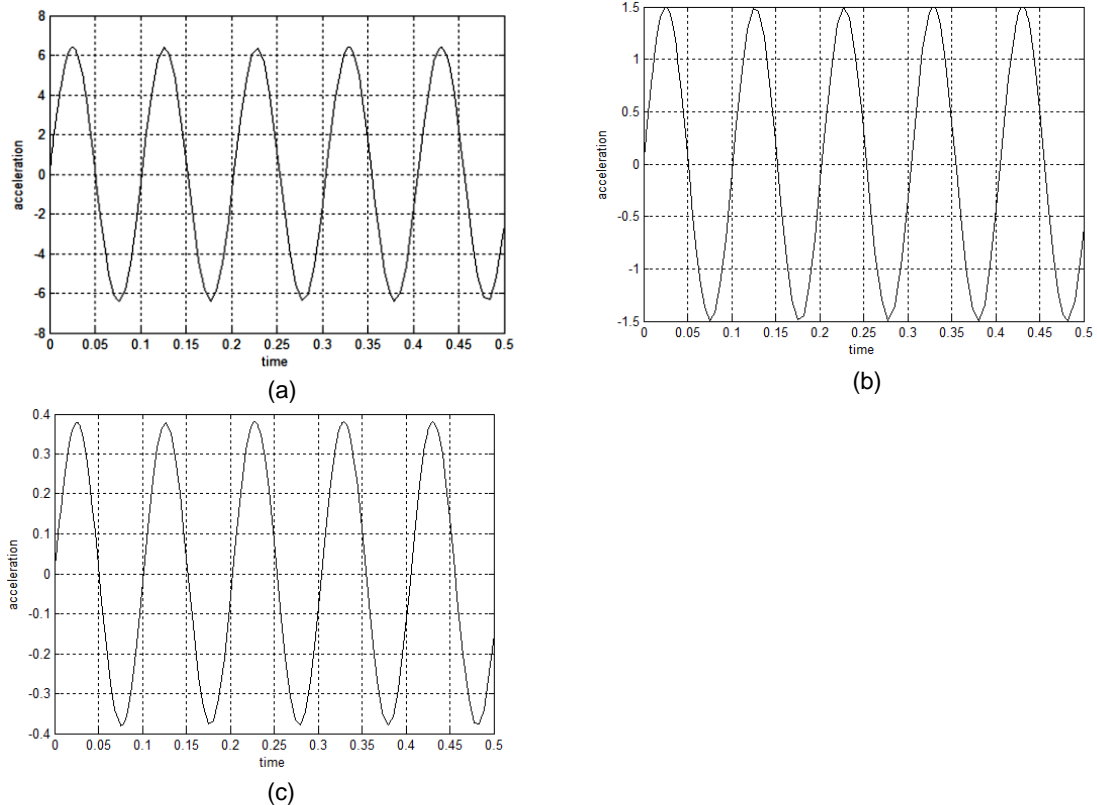


Figure 5: (a) Input vibration of kitchen blender casing. (b) Input vibration of ducting system. (c) Input vibration of piping system.

The acceleration is then fed into piezoelectric converter transfer function and a signal conditioning of non-adaptive rectifier circuit is employed to convert the alternate voltage produced by piezoelectric converter to direct voltage. Figures 6a, b, and c show the simulation output of alternate and direct voltage generated from the various vibration sources.

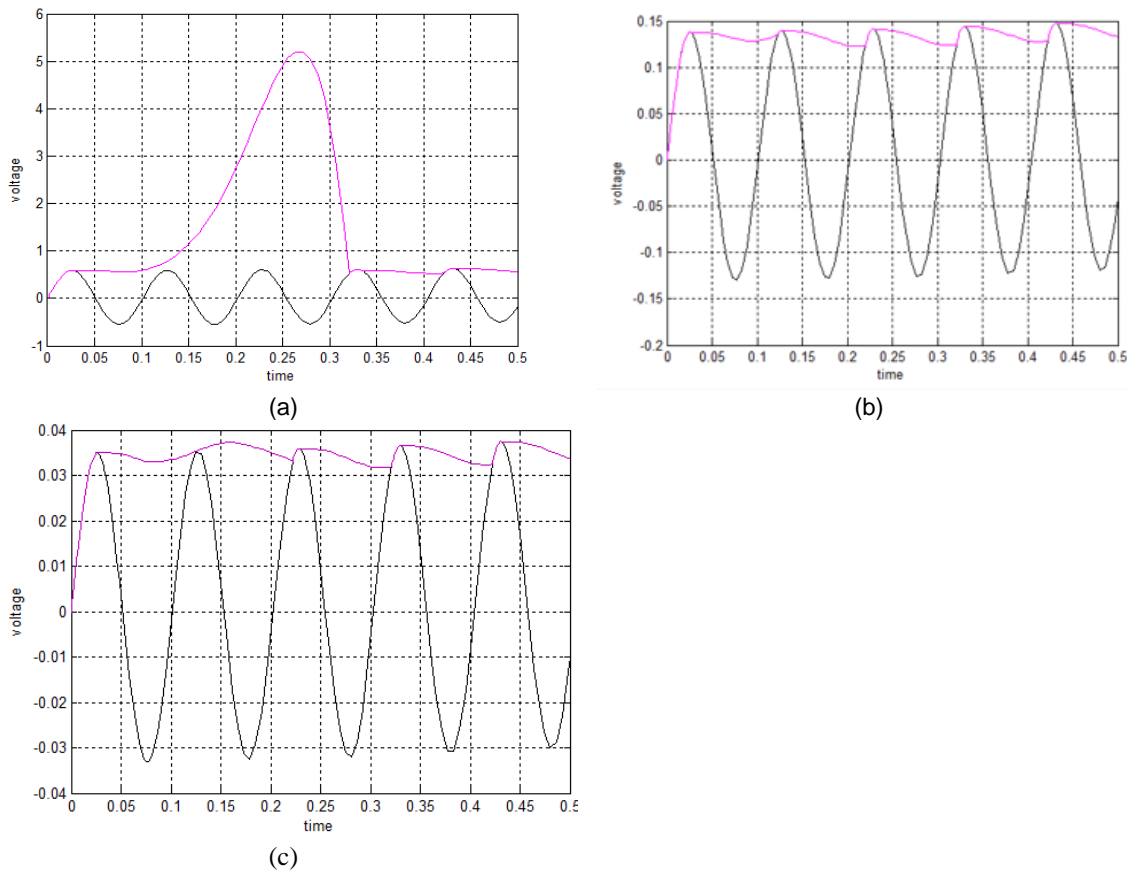


Figure 6: (a) Output voltage of kitchen blender casing. (b) Output voltage of ducting system. (c) Output voltage of piping system.

From Figure 6a, it is noted that there is an overshoot of voltage at the shape of the graph. This is due to the surge of current. According to Sree (2012), the surge current is a sudden increase of current or voltage that usually caused by unbalanced current or voltage. The small magnitude of surge current of transient voltages is enough to cause high temperature and voltage breakdown. In general terms, a surge is a sudden increase and electrical current is the rate of charge flows. This also explains that the model of piezoelectric converter for type PI P-876 DuraAct with maximum bending radius of 12 mm limits the input vibration not more than 6.4 m/s^2 and suitable for low level vibration only.

From Figures 6b and c, it shows that as the acceleration magnitude increases, the average direct voltage also increases from 0.035 V to 0.14 V . It also shows that as the direct voltage increases, the average power output that could be harnessed also increases. In simulation for input vibration of 1.5 m/s^2 from ducting system at 60 Hz , the maximal power output is 1.96 W . Table 3 summarizes all the results obtained through simulation using Matlab SIMULINK.

Table 3: Summary of simulation results

Vibration source	Acceleration of amplitude, m/s^2	Direct voltage, V	Power output, W
Kitchen blender casing	6.40	Unstable	
Ducting system	1.50	0.140	1.960
Piping system	0.38	0.035	0.123

From these results, it shows that a higher average power can be generated if the acceleration magnitude is larger which within the maximum limits of the converter. Produced power of 1.96 W is enough to light up a 1-Watt single mini LED light and sufficient for low-powered wireless sensor networks (Roundy et al., 2003).

5. Conclusions

Harvesting vibration energy from environment is one of the green technology approach and energy saving. It is best interest to study the vibration energy harnessing in applications that vibration is present. The piezoelectric model as vibration harvester using Matlab SIMULINK had been successfully developed. With the input vibration of 1.5 m/s² from ducting system, simulation results show that the maximal power output produced is 1.96 W. It also can be concluded that as the acceleration magnitude increases, the direct voltage and power generated are also increased.

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